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What proportion of renewable energy supplies is needed to initially mitigate CO_2 emissions in OECD member countries?

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ABSTRACT

In spite of increasing numbers of countries having established renewable energy development mechanisms for carbon dioxide (CO_2) emissions reduction, the CO_2 emissions problem continues to worsen along with the growth of the world economy. This leads us to examine the threshold effect of the proportion of renewable energy supply for CO_2 emissions reduction by means of the panel threshold regression model (PTR). Economic growth and the price of energy are also both taken into account in the model in measuring the specific influence that each of them has on CO_2 emissions. The empirical panel data encompass all 30 member countries of the OECD and cover a period of about a decade in length from 1996 to 2005. Our empirical results provide clear evidence of the existence of a single threshold effect that may be divided into lower and higher regimes. Based on the specific estimates of the slope coefficients in each regime distinguished, we find that a renewable energy supply accounting for at least 8.3889% of total energy supply would mean that CO_2 emissions would start to be mitigated. Furthermore, real GDP and the CPI of energy are significantly and positively and insignificantly and negatively correlated with CO_2 emissions, respectively. These findings lead us to conclude that the authorities ought to enhance the proportion of renewable energy supply to more than 8.3889% of all energy supplied, which might help resolve the dilemma between economic growth and CO_2 emissions. Realizing the effects of CO_2 emissions reduction via energy price reforms or the levying of a carbon tax levy may, however, still remain a puzzle.

Contents

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1. Introduction

The Kyoto Protocol, which came into force on February 16, 2005, places obligations on all signatories to ensure that greenhouse gas emissions in 2012 are no greater than the total of such emissions in 1990. Many of the countries that seek to achieve this goal focus on three main strategies that are available to them for decreasing the amount of carbon dioxide (CO_2), namely, the greater efficiencies in electricity generation, as well as the recycling, capturing, utilization, disposal/storage, and use of renewable and nuclear sources of energy [1]. These strategies also suggest that fossil energy use be diminished based on well-established substitution by renewable energies. Nevertheless, most renewable sources are weaker economically than fossil fuel sources. This is a reason why many countries provide incentives (e.g., feed-in-tariffs, investment subsidies and tax credits, etc.) to enhance the proportion of their renewable energy supply.

Renewable energy gives rise to fewer CO_2 emissions than fossil energy such as biomass, and even zero emissions in the case of wind power, solar photovoltaic, etc. A substantial reduction in CO_2 emissions can be achieved through a large-scale integration of renewable energy supply into the energy system. Previous studies simulate optimal scenarios of the joint linear or nonlinear effects of renewable energy supply on CO_2 emissions reduction. The results describe the positive relationship between renewable energy supply and CO_2 emissions reduction after renewable sources are included in a portfolio for the energy system [2–9]. It is found that renewable energy has developed rapidly with a consensus being reached in CO_2 emissions reduction and with the high volatility in crude oil prices in recent years. The global temperature continues to increase year by year as usual. This phenomenon has led to increased interest in reestimating the specific effects both below and above the optimal threshold parameter of the proportion of renewable energy supply for CO_2 emissions reduction. Furthermore, we investigate the individual relationships between CO_2 emissions, economic growth and the energy price. These latter two are proxied by real gross domestic product (GDP) and the consumer price index (CPI) of energy, respectively.

In the current academic literature, there is evidence that with more economic growth, energy consumption has increased. The significant positive relationship between economic growth and CO_2 emissions has been clearly observed [10–15]. One strand of the literature has investigated the existence of a causal relationship between the greenhouse gas emissions and economic growth indices using multiple tests on climate change such as the famous Environmental Kuznets Curve which summarizes the relationship as taking the form of an inverted U-shape [16–18]. Another line of investigation in terms of the causality issue of economic growth and CO_2 emissions is based on time series or panel data econometric techniques, such as unit root tests, cointegration and the related error correction model. The nature of the causality between per capita GDP and per capita CO_2 emissions, short-run dynamic comovements and long-run cointegration has been explored [19]. These conclusions in the literature would appear to suggest that the authorities ought to exercise caution due to the dilemma that exists between economic development and environmental protection in terms of the long-run balanced relationship.

The debate on CO_2 emissions reduction in light of the steep increases in energy prices is never-ending. Intuitively, the energy consumption will decline as energy prices are raised, thereby resulting in a decrease in CO_2 emissions. High energy prices lead to a significant reduction in the total primary energy supply and this is combined with structural changes in primary energy supply in view of the smaller quantities of oil and natural gas through a noticeable increase in renewable energy sources [20]. Energy price reform has thus become a crucial element in the promotion of energy conservation, a reduction in CO_2 emissions and the substitution of fossil fuels with renewable energy. Deregulating energy prices and imposing different levels of taxation on fossil fuels could decrease CO_2 emissions without considerably suppressing the growth of the economy. However, these policies cannot cope with the inevitable increased use of coal in the long run [21]. The literature thus induces us to hypothesize that an uncertain negative relationship exists between energy prices and CO_2 emissions.

We examine the panel threshold regression model (hereafter, PTR) that was previous described, whose estimation methodology is developed for non-dynamic panels with individual specific fixed effects. Least squares estimation of the threshold and regression slopes is proposed using fixed-effects transformations. A non-standard asymptotic theory of inference and a bootstrap method are also imposed which allows for the construction of confidence intervals to assess the statistical significance of the threshold effect and the testing of hypotheses [22]. The PTR model can then estimate the optimal threshold parameter which is divided into lower and higher regimes. There is a specific estimation of the slope coefficient in each regime. Our empirical panel data set is formed across all 30 member countries of the Organisation for Economic Co-operation and Development (OECD)[1] and the sample period spans a decade from 1996 to 2005.

The most important contribution of this paper is that we are able to determine the optimal proportion of renewable energy supply for CO_2 emissions reduction. Our empirical results show that only the single threshold effect is explored. The estimated specific slope coefficients for the lower and higher regimes have a completely opposite significance to those for CO_2 emissions. We might interpret this robust evidence as indicating that the proportion of renewable energy supply is at least more than 8.3889% (of the estimated optimal threshold parameter) that would initially mitigate CO_2 emissions.

Other empirical results also show that real GDP is both significantly and positively correlated with CO_2 emissions. This relationship implies that economic growth will increase the environmental impact as global temperatures abnormally rise. An analogous financial instrument is a carbon tax which has a similar effect in terms of raising energy prices for mitigated CO_2 emissions [23–25]. There is an insignificant negative relationship between the CPI of energy and CO_2 emissions. Hence realizing the effects of a reduction in CO_2 emissions via energy price reform or a carbon tax levy may still be a puzzle. To sum up, our empirical findings lead us to conclude that the authorities ought to enhance the proportion of renewable energy supply by more than 8.3889%, if the dilemma between economic growth and CO_2 emissions is to be resolved.

The remainder of this paper is organized as follows. Section 2 describes the PTR model estimation methodology. Section 3 describes how the panel data are formed. Section 4 presents the results of the estimation which are robust with respect to the threshold effect. The final section summarizes our empirical findings and enables us to draw conclusions.

[1] member countries of the OECD are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.

2. The methodology

2.1. Single threshold estimation

The empirical data is from a balanced panel. Our empirical objective is to examine whether there exists a renewable energy supply threshold effect for a reduction in CO_2 emissions. In order to present the notation, let the dependent variable $CO2_{it}$ be the annual growth in terms of the percentage of CO_2 emissions, the independent variable GDP_{it} be the annual growth in terms of the percentage of real GDP, CPI_{it} be the annual growth in terms of the percentage of the CPI of energy, and RES_{it} be the annual contribution of renewables to energy supply. The single threshold estimation of the PTR model as follows:

$$CO2_{it} = \mu_i + \beta_1' GDP_{it} + \beta_2' CPI_{it} + \beta_3' RES_{it} I(RES_{it} \leq \gamma) + \beta_4' RES_{it} I(RES_{it} > \gamma) + e_{it} \tag{1}$$

where intercept term μ_i is implied the individual specific mean. The subscript i indexes the individual, the subscript t indexes times and $I(\ )$ is the indicator function. GDP_{it}, CPI_{it} and RES_{it} are used to measure the specific influences on $CO2_{it}$ simultaneously. The other RES_{it} in the indicator functions $I(\ )$ is the threshold variable which is used to estimate the optimal threshold parameters $\hat{\gamma}$. There are diverse into lower or higher regimes for which the specific estimates of the slope coefficients are β_3' and β_4' for each regime distinguished. The error term e_{it} is assumed to be independent and identically distributed (iid) with mean zero and finite variance σ^2.

2.2. Estimation

An alternative compact representation of (1) is to set $RES_{it}(\gamma) = \begin{pmatrix} RES_{it} I(RES_{it} \leq \gamma) \\ RES_{it} I(RES_{it} > \gamma) \end{pmatrix}$ and $\beta = (\beta_3' \quad \beta_4')$ so that (1) equals

$$CO2_{it} = \mu_i + \beta_1' GDP_{it} + \beta_2' CPI_{it} + \beta' RES_{it}(\gamma) + e_{it} \tag{2}$$

One traditional method to estimate (2) that to remove individual effect μ_i that taking averages (1) over the time index t produces

$$\overline{CO2}_i = \mu_i + \beta_1' \overline{GDP}_i + \beta_2' \overline{CPI}_i + \beta' \overline{RES}_i(\gamma) + \bar{e}_i \tag{3}$$

Taking the difference between (2) and (3) for de-mean that yields

$$CO2_{it}^* = \beta_1' GDP_{it}^* + \beta_2' CPI_{it}^* + \beta' RES_{it}^*(\gamma) + e_{it}^* \tag{4}$$

For any given γ, the slope coefficient β can be estimated by ordinary least squares (OLS). The sum of squared error is calculated by

$$S_1(\gamma) = \hat{e}^*(\gamma)' \hat{e}^*(\gamma) \tag{5}$$

Estimation of γ by least squares is easiest to achieve by minimization of the concentrated sum of squared errors $S_1(\gamma)$ [26,27]. Hence the least squares estimators of γ is

$$\hat{\gamma} = \underset{\gamma}{\operatorname{argmin}}\, S_1(\gamma) \tag{6}$$

Once $\hat{\gamma}$ is obtained, the slope coefficient estimate is $\hat{\beta} = \hat{\beta}(\hat{\gamma})$. The residual vector is $\hat{e}^* = \hat{e}^*(\hat{\gamma})$ and residual variance

$$\hat{\sigma}^2 = \hat{e}^{*'} \hat{e}^* / n(T-1) = S_1(\hat{\gamma}) / n(T-1) \tag{7}$$

where n indexes the number of sample, T indexes the period of sample.

2.3. Testing for single threshold

There is important to determine whether the threshold effect is statistically significant. The null hypotheses of no threshold effect H0: $\beta_3 = \beta_4$ in (1). Under this null hypothesis of no threshold, the model (1) is reduce as

$$CO2_{it} = \mu_i + \beta_1' GDP_{it} + \beta_2' CPI_{it} + \beta_3' RES_{it} + e_{it} \tag{8}$$

The regression parameter β_3 is estimated by OLS, yielding coefficient $\tilde{\beta}_3$, residuals $\tilde{e}_{it}^*$ and sum of squared errors $S_0 = \tilde{e}^{*'} \tilde{e}^*$. The likelihood ratio test of H_0 is base on

$$F_1(\gamma) = \frac{S_0 - S_1(\hat{\gamma})}{\hat{\sigma}^2} \tag{9}$$

The asymptotic distribution of $F_1(\gamma)$ is non-standard, and strictly dominates the X_k^2 distribution. A bootstrap procedure attains the first-order asymptotic distribution which the null of no threshold effect is rejected if $F_1(\gamma)$ is higher than the desired critical value [28].

When there is a threshold effect ($\beta_1 \neq \beta_2$), that $\hat{\gamma}$ is consistent for γ_0 (the true value γ). The best way to form confidence intervals for γ is to form the no-rejection region using the likelihood ratio statistic for tests on γ [27]. The null hypotheses is H0: $\gamma = \gamma_0$, the likelihood ratio test is to reject for large values of $LR_1(\gamma_0)$ where

$$LR_1(\gamma) = \frac{S_1(\gamma) - S_1(\hat{\gamma})}{\hat{\sigma}^2} \tag{10}$$

The theorem $LR_1\gamma \to d\xi$, as $n \to \infty$, where ξ is a random variable with distribution function

$$P(\xi \leq x) = \left(1 - \exp\left(-\frac{x}{2}\right)\right)^2 \tag{11}$$

The asymptotic distribution of the likelihood ratio statistic is non-standard yet free of nuisance parameters. The technical assumptions include the rather unusual condition that $\beta_4 - \beta_3 \to 0$ as $n \to \infty$. The asymptotic distribution may be used to valid asymptotic confidence intervals. The distribution function (11) has the inverse

$$c(\alpha) = -2\log(1 - \sqrt{1-\alpha}) \tag{12}$$

from which calculate critical values of rejects at the asymptotic level. For example, the 10%, 5% and 1% critical value are 5.94, 7.35 and 10.59, respectively.

2.4. Double threshold estimation

Extend model (1) has been double threshold model takes the form

$$CO2_{it} = \mu_i + \beta_1' GDP_{it} + \beta_2' CPI_{it} + \beta_3' RES_{it} I(RES_{it} \leq \gamma_1) + \beta_4' RES_{it} I(\gamma_1 < RES_{it} \leq \gamma_2) + \beta_5' RES_{it} I(\gamma_2 < RES_{it}) + e_{it} \tag{13}$$

Thus for given (γ_1, γ_2) the concentrated sum of squared errors $S(\gamma_1, \gamma_2)$ is straightforward to calculate as the single threshold model. Let $S_1(\gamma_1)$ be the single threshold sum of squared errors as defined in (5) and let $\hat{\gamma}_1$ be the threshold estimate which minimizes $S_1(\gamma)$. The $\hat{\gamma}_1$ will be consistent for either γ_1 or γ_2. Fixing the $\hat{\gamma}_1$, then criterion $S_2^{\gamma}(\gamma_2)$ is

$$S_2^r(\gamma_2) = \begin{cases} S(\hat{\gamma}_1, \gamma_2) & \text{if } \hat{\gamma}_1 < \gamma_2 \\ S(\gamma_2, \hat{\gamma}_1) & \text{if } \gamma_2 < \hat{\gamma}_1 \end{cases} \tag{14}$$

and threshold estimate $\hat{\gamma}_2^{\gamma}$ is

$$\hat{\gamma}_2^r = \underset{\gamma_2}{\operatorname{argmin}} S_2^r(\gamma_2) \tag{15}$$

Fixing the asymptotic efficiency of $\hat{\gamma}_2^r$ define the refinement criterion

$$S_1^r(\gamma_1) = \begin{cases} S(\gamma_1, \hat{\gamma}_2^r) & \text{if } \gamma_1 < \hat{\gamma}_2^r \\ S(\hat{\gamma}_2^r, \gamma_1) & \text{if } \hat{\gamma}_2^r < \gamma_1 \end{cases} \tag{16}$$

and the refinement estimate

$$\hat{\gamma}_1^r = \underset{\gamma_1}{\operatorname{argmin}} S_1^r(\gamma_1) \tag{17}$$

The minimizing sum of squared errors $S_2^r(\hat{\gamma}_2^r)$ with variance estimate $\hat{\sigma}^2 = S_2^r(\hat{\gamma}_2^r)/n(T-1)$. Thus an approximate likelihood ratio test of double thresholds can be base on the statistic

$$F_2(\gamma) = \frac{S_1(\hat{\gamma}_1) - S_2^r(\hat{\gamma}_2^r)}{\hat{\sigma}^2} \tag{18}$$

and construction of confidence intervals in the same way as previous Section 2.3 for the individual threshold parameter as

$$LR_2^r(\gamma) = \frac{S_2^r(\gamma) - S_2^r(\hat{\gamma}_2^r)}{\hat{\sigma}^2} \quad \text{and} \quad LR_1^r(\gamma) = \frac{S_1^r(\gamma) - S_1^r(\hat{\gamma}_1^r)}{\hat{\sigma}^2} \tag{19}$$

The computations of the least squares estimate of the threshold parameter γ, γ_1 and γ_2 involve the minimization problem (6), (15) and (17). Since the sum of squared error function $S_1(\gamma)$, $S_1^{\gamma}(\gamma_1)$ and $S_2^{\gamma}(\gamma_2)$ depends only through the indicator functions are step function with at most nT steps, with the steps occurring at distinct values of the observed threshold variable. Thus the optimization search describe above may be numerically intensive. One approach may be taken. Sort the distinct values of the observations on the threshold variable. Instead of searching over all values of threshold variable the search may be limited to specific quantiles. This greatly reduces the number of regressions performed in the search. For the empirical work, we use the grid {0.25%, 0.50%, 0.75%, 1.00%,..., 99.25%, 99.50%, 99075%, 100%} which contains 400 quantiles.

3. The data

The panel data set used in this study encompasses all 30 member countries of the OECD and the sample period extends over a decade from 1996 to 2005. The data are obtained from the OECD statistical database, and all variables are defined at the end of the year. One of the variables is the contribution of renewables to energy supply. The other variables are the specific growth in the percentage of CO_2 emissions from energy use, real GDP and the CPI of energy. It should be noted that we calculate the annual growth in percentage of CO_2 emissions, real GDP and the CPI of energy based on the logarithmic difference. The total number of observations for the cross-sectional and time series data is 300 for each variable.

Table 1 exhibits the summary statistics for each of the four variables. The sample mean of the annual growth in the percentage of CO_2 emissions from energy use is found to be positive and to be 1.1625%. This statistic indicates that the global greenhouse effect problem is continually being exacerbated by CO_2 emissions. On average, the annual contribution of renewables to energy supply is 12.1777%, and the standard deviation is 14.8662 or higher, which means that the development of renewable energy differs quite significantly among the member countries of the OECD. The maximum contribution of 73.8292% is found in Iceland in 2005, which means that this country has the highest renewable energy supply among the member countries of the OECD, with its average contribution exceeding 70% from 1996 to 2005 in each year. In fact, large-scale renewable sources of hydropower and geothermal power have been exploited in Iceland. In contrast, the minimum annual contribution of renewables to energy supply of 0.8095% is found in Korea in 1996. Only slight growth, as evidenced by the contribution of renewables to energy supply reaching 0.9615%, is found to have occurred a decade later.

Table 1 also reports that the sample mean of the annual growth in percentage terms of real GDP is positive and amounts to 3.1979%, having a standard deviation of 2.3053. Furthermore, the sample mean of the annual growth in terms of the percentage of the CPI of energy is positive and amounts to 6.3876%, with a standard deviation of 10.1142. Both statistics imply that the rapid rise in energy prices is accompanied by higher volatility. The maximum such price rise is 72.6484% in Turkey in 1996. This is the highest energy price growth recorded among the member countries of the OECD, for which the average fluctuation exceeded 40% in each year from 1996 to 2005. The Jarque-Bera statistical tests indicate that all variables significantly reject the normal distribution hypothesis at the 1% level, which indicates that the distribution of each time series is both leptokurtic and fat-tailed.

4. Empirical results

4.1. Threshold effect estimation and test

To determine the optimal threshold parameters from Eq. (13), we use least squares estimation, and allow for zero, one and two thresholds. The test statistics of $F_1(\gamma)$ and $F_2(\gamma)$ along with the bootstrap critical values are reported in Table 2. The test for a single threshold $F_1(\gamma)$ is 22.5729. There is a greater significance level than the 95% critical value which is 22.4047. The test for a double threshold $F_2(\gamma)$ is 18.4303. There is a significance level that is less than the 90% critical value that is 18.7472. These results provide strong evidence of only a single threshold effect being uncovered in the regression.

The point estimates of the threshold asymptotic 95% confidence intervals are also reported in Table 2. The estimation of $\hat{\gamma}_1$ yields a value of 8.3889 in the empirical distribution of the threshold variable. Thus the proportion of renewable energy supply has been separated into lower and higher regimes. The asymptotic confidence intervals for the threshold $\hat{\gamma}_1$ are very tight and lie within the range of 8.3889 to 8.3889, indicating that there is little uncertainty regarding the nature of this breakdown. The estimation of $\hat{\gamma}_2$ yields a higher value of 11.3122, for which the asymptotic confidence intervals are very wide and quite uncertain in that they range from 10.6473 to 23.3276. The findings are robust in that the lower regime $I(RES_{it} \le \hat{\gamma}_1)$ includes 182 (60.67%)

Table 1
Summary statistics.

Variable	Mean (%) (standard deviation)	Minimum (%)	Maximum (%)	Jarque-Bera (p-value)
Annual growth in percentage of CO_2 emissions from energy use	1.1625 (4.6680)	−21.7716	20.3322	126.2835 (0.0000)
Annual contribution of renewables to energy supply	12.1777 (14.8662)	0.8095	73.8292	749.0096 (0.0000)
Annual growth in percentage of Real GDP	3.1979 (2.3053)	−7.4954	11.6801	132.0706 (0.0000)
Annual growth in percentage of CPI of energy	6.3876 (10.1142)	−11.0988	72.6484	3341.9191 (0.0000)

Table 2
Threshold estimates.

Threshold variable	Parameter (95% confidence interval)	$F(\gamma)$ (10%, 5%, 1% critical values)
$\hat{\gamma}_1$	8.3889* (8.3889, 8.3889)	22.5729 (19.7475, 22.4047, 26.1675)
$\hat{\gamma}_2$	11.3122 (10.6473, 23.3276)	18.4303 (18.7472, 20.1217, 22.7566)

Note: The critical values are simulated by bootstrap method.
* Significance at the 5% level.

observations and the relatively higher regime $I(RES_{it} > \hat{\gamma}_1)$ includes 118 (39.33%) observations. These results reveal that the single threshold model conveys information that is only found in the regression and the optimal threshold parameter is 8.3889%.

Figs. 1 and 2 depict the construction of the confidence intervals for the single and double threshold models, respectively. The horizontal axis denotes the estimation of the first and second threshold parameters and the vertical axis expresses the concentrated individual likelihood ratio function $LR_1^{\gamma}(\gamma)$ and $LR_2^{\gamma}(\gamma)$. The point estimates are the values of $\hat{\gamma}_1$ and $\hat{\gamma}_2$ where the likelihood ratios $LR_1^{\gamma}(\gamma)$ and $LR_2^{\gamma}(\gamma)$ intersect the zero horizontal axis, which is in the far left part of the graph. The 95% confidence intervals for γ_1 and γ_2 can be found from $LR_1^{\gamma}(\gamma)$ and $LR_2^{\gamma}(\gamma)$ based on the values of γ_1 and γ_2 for which the likelihood ratio lies beneath the dotted line at 7.35. This critical value is calculated using formula (12).

4.2. Regression estimation

According to the specification in the preceding section, a single threshold effect is found to exist. Thus the remainder of Eq. (13) may be reduced according to the class of model (1). Where the regression slope estimates contain conventional OLS standard errors and White-corrected standard errors which are reported in Table 3. Only the coefficient β_2 is insignificant, and β_1 is 0.4630 at the 1% significant level. There is an obvious positive relationship between real GDP and CO_2 emissions as the findings indicate in the previous literature, where an expansion in real GDP results in increased CO_2 emissions. More fossil fuels are consumed as economic growth increases, as fossil fuels are more stable and also more efficient than renewable sources of energy. Moreover, fossil fuels also provide cheaper electricity and fuel that further encourage economic growth. The coefficient β_2 is very small and negative as shown by its value of −0.0002, which indicates that an uncertain negative relationship exists between the price of energy and CO_2 emissions. Consequently, as to whether rising energy prices via a demand/supply matching mechanism or a carbon tax levy would benefit a reduction in CO_2 emissions is a question that still remains unanswered in spite of our empirical findings.

Table 3 also indicates that the coefficients of primary interest are those to do with the annual contribution of renewables to energy supply. When the proportion of renewable energy supply in one of our regimes is equal to or lower than the optimal threshold parameter $\hat{\gamma}_1$, the specific estimation of the slope coefficient β_3 is 1.1162 at the 5% significance level. An obvious positive relationship implies that, in spite of the increased proportion of renewable energy supply, there is no effect that will help mitigate CO_2 emissions which will continue to increase. In another of the regimes selected, the proportion of renewable energy supply is higher than the optimal threshold parameter $\hat{\gamma}_1$, with the specific estimation of the slope coefficient β_4 being −0.9186 at the 1% significant level. There is an obvious negative relationship that leads to a reasonable explanation in that the increased economic growth leads to increased energy consumption. Thus a smaller proportion of renewable energy supply fails to generate a real substitutive effect of CO_2 emissions for fossil energy. It is also interesting to note that only when the proportion of renewable energy supply is at least more than 8.3889% (the optimal threshold parameter) will CO_2 emissions start to be mitigated. If this is the case, we would like to suggest that the authorities increase the proportion of renewable energy supply to more than 8.3889%, which might help resolve the dilemma between economic growth and CO_2 emissions.

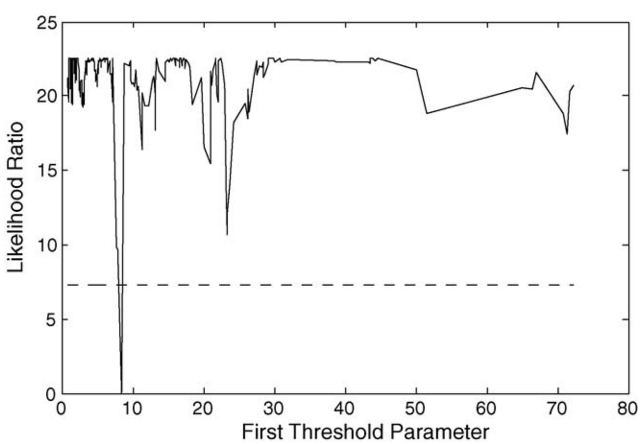


Fig. 1. Confidence interval construction in single threshold model.

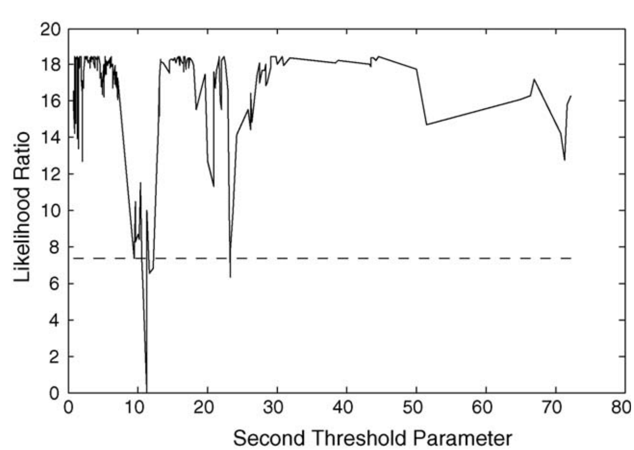


Fig. 2. Confidence interval construction in double threshold model.

Table 3
Regression estimates: single threshold model.

Variable	Coefficient	OLS standard error	White standard error
β_1	0.4630**	0.1256	0.1792
β_2	−0.0002	0.0366	0.0382
β_3	1.1162*	0.4875	0.5638
β_4	−0.9186**	0.1893	0.2617

* Significance at the 5% level.
** Significance at the 1% level.

5. Conclusions

We are concerned with the phenomenon that renewable energy supplies may fail to resolve the greenhouse gas emissions problem even after renewable sources of energy are included in a portfolio of the energy system. Hence we recommend that the PTR model be used to examine the threshold effect of the proportion of total energy to be accounted for by renewable energy supply to give rise to a reduction in CO_2 emissions. Real GDP and the CPI of energy are also included in the model to measure their specific influences on CO_2 emissions simultaneously.

Our empirical approach involves using panel data which encompass all 30 member countries of the OECD over a sample period spanning a decade from 1996 to 2005. The empirical tests that examine only a single threshold effect are also explored. The threshold effect is divided into both lower and higher regimes. There is a complete reversal of the specific estimation of the slope coefficient between each distinguished regime. The real GDP and the CPI of energy are significantly and positively and insignificantly and negatively correlated with CO_2 emissions, respectively.

To sum up, our empirical findings lead to the conclusion that the demand for more fossil fuel consumption resulting from increased economic growth will speed up the generation of CO_2 emissions. Thus the authorities ought to increase the proportion of total energy sources accounted for by renewable energy supply to more than 8.3889%, which might help to solve the growing dilemma between economic growth and CO_2 emissions within the framework of the Kyoto Protocol. Realizing the effects of reducing CO_2 emissions via an energy price reform or a carbon tax levy, however, still remains a puzzle.

References

[1] Gessinger G. Lower CO_2 emissions through better technology. Energy Convers Manage 1997;38:25–30.
[2] Wisniewski G, Rogulska M, Grzybek A, Pietruszko SM. The role of renewable energy in carbon dioxide emission reduction in Poland. Appl Energy 1995;52:291–8.
[3] Molt S, Schaumann P, Laege E, Fahl U, Voss A. Integrated strategies to reduce Greenhouse gas emissions in Germany. Energy Convers Manage 1996;37:735–40.
[4] Mirasgedis S, Sarafidis Y, Georgopoulou E, Lalas DP. The role of renewable energy sources within the framework of the Kyoto Protocol: the case of Greece. Renew Sust Energy Rev 2002;6:247–69.
[5] Kaygusuz K. Energy policy and climate change in Turkey. Energy Convers Manage 2003;44:1671–88.
[6] Tanatvanit S, Limmeechokchai B, Chungpaibulpatana S. Sustainable energy development strategies: implications of energy demand management and renewable energy in Thailand. Renew Sust Energy Rev 2003;7:367–95.
[7] Hernández F, Gual MÁ, Río PD, Caparrós A. Energy sustainability and global warming in Spain. Energy Policy 2004;32:383–94.
[8] Kelly N. The role of energy efficiency in reducing Scottish and UK CO_2 emissions. Energy Policy 2006;34:3505–15.
[9] Moreno B, López AJ. The effect of renewable energy on employment: the case of Asturias (Spain). Renew Sust Energy Rev 2008;12:732–51.
[10] Shafik N. Economic development and environmental quality: an econometric analysis. Oxford Econ Pap 1994;46:757–73.
[11] Tucker M. Carbon dioxide emissions and global GDP. Ecol Econ 1995;15:215–23.
[12] Coondoo D, Dinda S. Causality between income and emission: a country group-specific econometric analysis. Ecol Econ 2002;40:351–67.
[13] Fan Y, Liu LC, Wu G, Wei YM. Analyzing impact factors of CO_2 emissions using the STIRPAT model. Environ Impact Assess Rev 2006;26:377–95.
[14] Onishi A. The impact of CO_2 emissions on the world economy: Policy simulations of FUGI global model. J Policy Model 2007;29:797–819.
[15] Li J, Song H, Geng D. Causality relationship between coal consumption and GDP: Difference of major OECD and non-OECD countries. Appl Energy 2008;85:421–9.
[16] Suri V, Chapman D. Economic growth, trade and energy: implications for the environmental Kuznets curve. Ecol Econ 1998;25:195–208.
[17] Agras J, Chapman D. A dynamic approach to the Environmental Kuznets Curve hypothesis. Ecol Econ 1999;28:267–77.
[18] Friedl B, Getzner M. Determinants of CO_2 emissions in a small open economy. Ecol Econ 2003;45:133–48.
[19] Dinda S, Coondoo D. Income and emission: a panel data-based cointegration analysis. Ecol Econ 2006;57:167–81.
[20] Martinsen D, Krey V, Markewitz P. Implications of high energy prices for energy system and emissions—the response from an energy model for Germany. Energy Policy 2007;35:4504–15.
[21] Sasmojo S, Tasrif M. CO_2 emissions reduction by price deregulation and fossil fuel taxation: a case study of Indonesia. Energy Policy 1991;19:970–7.
[22] Hansen BE. Threshold effects in non-dynamic panels: Estimation, testing, and inference. J Econom 1999;93:345–68.
[23] Ekins P. How large a carbon tax is justified by the secondary benefits of CO_2 abatement? Resour Energy Econ 1996;18:161–87.
[24] Al-Abdullah AY. The carbon-tax debate. Appl Energy 1999;64:3–13.
[25] Borchiellini R, Massardo AF, Santarelli M. Analytical procedure for carbon tax evaluation. Energy Convers Manage 2000;41:1509–31.
[26] Chan KS. Consistency and limiting distribution of the least squares estimator of a threshold autoregressive model. Ann Stat 1993;21:520–33.
[27] Hansen BE. Sample splitting and threshold estimation. Econometrica 2000;68:575–603.
[28] Hansen BE. Inference when a nuisance parameter is not identified under the null hypothesis. Econometrica 1996;64:413–30.